1449.

BACK-UP OF
RECOGNITION OF POISSONS RATIO

CORRECTED VERSION *

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : B65H 26/02	A1	(11) International Publication Number: WO 92/19522 (43) International Publication Date: 12 November 1992 (12.11.92)

(21) International Application Number: PCT/US92/03525

(22) International Filing Date: 30 April 1992 (30.04.92)

(30) Priority data:
695,621 3 May 1991 (03.05.91) US

(71) Applicant: EASTMAN KODAK COMPANY [US/US]; 343 State Street, Rochester, NY 14650 (US).

(72) Inventor: HAKIEL, Zbigniew ; 1154 Hidden Valley Trail, Webster, NY 14580 (US).

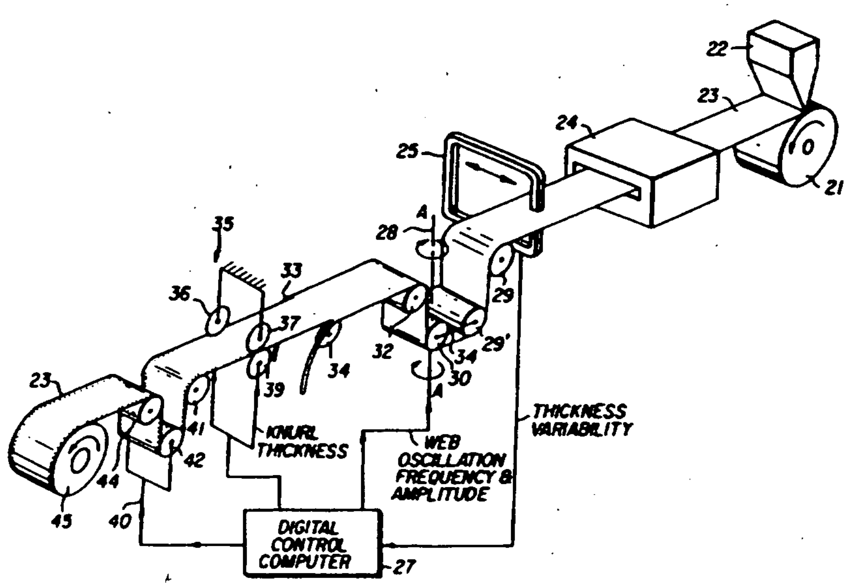
(74) Agent: RUOFF, Carl, F.; 343 State Street, Rochester, NY 14650-2201 (US).

→ X 1
p 17 l 9
p 18 l 15 – 23
clm 1

(81) Designated States: AT (European patent), BE (European patent), CH (European patent), DE (European patent), DK (European patent), ES (European patent), FR (European patent), GB (European patent), GR (European patent), IT (European patent), JP, LU (European patent), MC (European patent), NL (European patent), SE (European patent).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: CONTROL OF WEB WINDING



(57) Abstract

In the winding of webs of plastic films, defects in the web caused by hard streaks in the wound roll are avoided or reduced by a new method of control. In this method, measurements are made of elastic properties of the web and of the average widthwise thickness distribution of the web. From these values and from selected initial winding conditions, including web tension, edge thickness and web oscillation conditions, potential web defects are predicted. These are compared with acceptable tolerances and, if excessive, the winding conditions are optimized to reduce the predicted web defects and the next roll is wound under such optimized conditions.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	ES	Spain	MG	Madagascar
AU	Australia	FI	Finland	ML	Mali
BB	Barbados	FR	France	MN	Mongolia
BE	Belgium	GA	Gabon	MR	Mauritania
BF	Burkina Faso	GB	United Kingdom	MW	Malawi
BG	Bulgaria	GN	Guinea	NL	Netherlands
BJ	Benin	GR	Greece	NO	Norway
BR	Brazil	HU	Hungary	PL	Poland
CA	Canada	IT	Italy	RO	Romania
CF	Central African Republic	JP	Japan	RU	Russian Federation
CG	Congo	KP	Democratic People's Republic of Korea	SD	Sudan
CH	Switzerland			SE	Sweden
CI	Côte d'Ivoire	KR	Republic of Korea	SN	Senegal
CM	Cameroon	LI	Liechtenstein	SU	Soviet Union
CS	Czechoslovakia	LK	Sri Lanka	TD	Chad
DE	Germany	LU	Luxembourg	TG	Togo
DK	Denmark	MC	Monaco	US	United States of America

CONTROL OF WEB WINDING

Field of Invention

This invention relates to the winding of plastic webs and, more particularly, to a method of controlling web winding to avoid or reduce the creation of defects in the web.

Background

Plastic webs such as photographic film bases, that are made by continuous extrusion or melt casting, often exhibit widthwise thickness variations (distribution of thickness across the width of the web) which are persistent in the lengthwise direction. These thickness variations are sometimes called gauge bands or thick/thin streaks. When webs having such gauge bands are wound into rolls, hardstreaks (also called ridges) can form in the winding roll. Hardstreaks are annular bands in the winding roll that are parallel to the sidewall of the roll. Where hardstreaks occur the diameter of the winding roll is increased and the pressure between layers in the wound roll is concentrated in this area. Hardstreaks are objectionable because they can lead to web imperfections including: distortions, pressure damage to sensitive coatings and adhesion or blocking of adjacent layers or laps in the wound roll.

To minimize the effect of such thickness variations, both edges of the web can be thickened through an embossing or knurling process and/or the web can be oscillated laterally during winding. Knurling creates artificially thickened areas at the edges of the web which, upon winding, create intentional hardstreaks at the edges. By creating these artificial hardstreaks at the edges in the nonusable portions of the web, a substantial part of the winding tension is used up and

the effective tension in the middle portion of the web is significantly reduced, thereby reducing the severity of any hardstreaks which may form in the usable middle part of the web.

Oscillation, as in U.S. Patents Nos. 2,672,299 and 4,453,659, offsets any thickened portions of the web to reduce the build up of thickness in a particular lateral portion of the wound roll. Although oscillation (also called "wiggle-winding" and "stagger winding") can reduce the development of hardstreaks in the wound web, it can also cause an undesirable amount of edge waste if the oscillation amplitude is large. On the other hand, if the oscillation amplitude is not sufficiently great, the gauge bands in the web are not offset enough to prevent or reduce the formation of hardstreaks.

Although thickening the edges can reduce the hardstreak problem, if they are too thick, i.e., if the "knurl height" is too great, other problems are caused. Thus, if the edges are too thick, the web will be supported solely at the thick edges and buckling will occur in middle of the roll. Also, if all of the roll tension is carried at the edges of the web, the high pressure at the thickened edges can result in "telescoping" or lateral shifting of laps of the roll because of instability in the widthwise direction. Therefore, to reduce the hardstreak problem without creating other problems it is necessary to determine an optimum edge thickness or knurl height for the web.

Similar considerations apply to the tension in the web during winding. Although lowering of tension can reduce hardstreaks, if the tension is too low other problems occur. In particular, at excessively low tension a slippage between layers occurs, a problem known in the art as cinching. Likewise, excessively low tension can cause telescoping or roll shifting.

The described problems can occur in the winding of a wide range of plastic web sizes. The problems are especially serious, however, in the winding of wide plastic webs, e.g., 40 to 80 inches in width, to form large rolls, e.g., of 1.5 to 5 feet in diameter, and especially when the web comprises a thermoplastic film base or support which is coated with one or more photographically sensitive layers and other layers. Such webs are especially susceptible to hardstreak formation, and the waste created by hardstreaks is especially costly. As a consequence a need exists for a method for controlling the winding of plastic webs so that the severity of hardstreaks in the wound web can be minimized without creating other problems.

<u>Brief Summary of the Invention</u>

In accordance with the present invention a method is provided for controlling web winding which reduces or eliminates the mentioned problems, especially for wide webs and rolls of large diameter as indicated above. The novel method includes steps which are carried out by automatic data processing equipment employing an analytical model which predicts winding imperfections and facilitates selection of optimum winding conditions to minimize the severity of winding imperfections. Variables which are factors in the model include thickness variations of the web, the winding conditions, dimensions and stiffness of the core, and elastic properties of the web.

The method of the invention comprises:

measuring properties of a plastic web to be wound on a core including:

(a) modulus of elasticity of the plastic,

(b) stack-wise compression modulus of the web,

(c) stack-wise compression modulus of the thickened edges,

(d) Poisson's ratio of the plastic, and

(e) stress relaxation modulus of the web;

selecting values for at least one of

(a) initial web tension,

(b) initial edge thickness, and

(c) initial web oscillation,

measuring widthwise thickness variations of said web at lengthwise locations on the web,

averaging the measured widthwise thickness variations in the lengthwise direction to obtain an average widthwise thickness distribution for the web,

measuring the core modulus and the width and diameter of the core,

predicting the severity of winding imperfections, from the relationship of (1) said properties, (2) the thickness distribution, (3) the values of initial web tension, initial edge thickness and initial web oscillation, and (4) the measurements of the core, preferably in accordance with the analytical model shown in Figs. 3a and 3b, the parameters of which are defined in Table I;

comparing the predicted imperfections with predetermined tolerances to determine whether the imperfections are within or exceed the tolerances;

when said predicted imperfections are within the tolerances, winding the web on the core at said initial web tension, edge thickness and web oscillation; and

when said predicted imperfections exceed the tolerances, winding the web on the core under corrected conditions including adjustment of at least one of (a) web tension, (b) edge thickness and (c) web oscillation.

The Drawings

Fig. 1 is a diagrammatic view in perspective of a wound roll of a plastic film web having knurled edges and exhibiting hard streaks in the roll and distortions in the film surface;

Fig. 2 is a diagrammatic view of a line for extruding and winding a plastic film web, with controls of the winding conditions in accordance with the invention;

Fig. 3a is the first part of a flow chart of the analytical model for predicting web imperfections;

Fig. 3b a continuation and completion of the flow chart of Fig. 3a;

Fig. 3c is the first part of a word description flow chart corresponding to Fig. 3a, which explains the programming of the model;

Fig. 3d is a continuation and completion of the word description flow chart and corresponds to Fig. 3b;

Fig. 3e is a schematic diagram of the method of the invention which uses the analytical model of Figs. 3a-3d;

Fig. 4 is plot showing a widthwise thickness distribution of a film web; and

Figs. 5, 6, 7 and 8 are predicted plots of the widthwise radius variations for a roll of film wound under three different combinations of winding conditions at different stages in the winding of the roll.

Detailed Description of the Invention

Definitions:

(a) "modulus of elasticity of the plastic" means the ratio of stress to the corresponding strain (lb/in^2).

(b) "compressive elastic modulus of the web" means the modulus of a stack of sheets of the web material in compression (lb/in^2).

(c) "compressive modulus of the thickened edges" means the modulus of a stack of the knurled or thickened edges (lb/in^2).

(d) "Poisson's ratio of the plastic" means the ratio of the contraction of the lateral dimensions of the sample to the strain or unit elogation (elongation per unit of length). <u>This ratio, c/s, is constant for a given plastic material within the elastic limit.</u>

(e) "core modulus" is an expression of the radial stiffness of the core at its periphery, as defined by Equation 8 of Hakiel, TAPPI Journal, Vol. 70, No. 5, p. 114 (May 1987) (lb/in^2).

(f) "stress relaxation modulus of the web" means the time-dependent value of stress divided by the constant strain for a stretched sample of the web (lb/in^2).

In the method of the present invention, winding imperfections caused by lengthwise persistent widthwise thickness variations are avoided or reduced by the use of an analytical model in either an off-line or an automated on-line calculation to select optimum winding process conditions. The method is carried out under winding conditions determined by a computer that is programmed in accordance with Figs. 3a and 3b.

One step in the computerized method is to obtain multiple measurements of widthwise thickness variability of the web, preferably on-line with a non-contacting device, and averaging these measurements in the lengthwise direction to obtain an average widthwise thickness distribution.

Web properties, including lengthwise modulus of elasticity in tension, stack-wise compression modulus, Poisson's ratio and stress relaxation modulus of the web in tension, are also measured and input into the analytical model. The dimensions of the core (length and diameter) upon which the web will be wound are also

input. In addition, starting values for the winding conditions, including winding tension, knurl or edge thickness of the web and web oscillation conditions, are selected, usually based on values for a previously wound roll.

Once this information is available and prior to winding the roll, the model is executed and the severity of the winding imperfections is predicted, including distortions, pressure damage to sensitive coatings and adhesion.

The predicted imperfection severity is compared with the predetermined tolerances for these imperfections. If the severity is acceptable, i.e. within the tolerances, the initial winding conditions are used to wind the roll and the process is repeated for the next roll. However, if the predicted imperfections are outside of the tolerance range, the following corrective action is undertaken.

An optimization routine is invoked, such as linear programming, which uses the combined value of the severity of all of the imperfections as the function to be minimized. This routine evaluates the combined value of the severity of all of the imperfections at numerous values of winding tension and knurl height in order to find the optimum combination which results in the minimum value of imperfections severity. Once such minimum is found, the corresponding values of winding tension and knurl height are used to wind the roll, the initial values are updated with the new values and the process is repeated for the next roll. Such linear programming is well known as exemplified by the disclosure in Chapter 10(10.8), pp. 312-326 of "Numerical Recipes, The Art of Scientific Computing" by Press et al., Cambridge University Press (1986).

To illustrate how this new procedure can be applied to a particular web winding operation, reference will be made to the drawings.

As shown in Fig. 1, a roll 10 of a polyester plastic film 11 is wound on a metal or plastic core 12. Extending along each edge of the film 11 are thickened areas or knurls 13 and 14. Fig. 1 represents a roll in which, because of the winding conditions, defects have been created in the roll and in the surface of the web. The roll defects are the hardstreaks or gauge bands 15 and 16. These are annular portions of the roll of substantially greater diameter than the rest of the roll.

A result of the formation of the hardstreaks 15 and 16 is that the web in the area of the hardstreaks is under excessive radial pressure. As Fig. 1 shows, this results in web defects. These are depicted in Fig. 1 as distortions 17, which can take the form of a line of intermittent, closely spaced dimples, puckers or dents in the surface of film 11. By the method of the present invention the creation of such defects is reduced or eliminated.

Fig. 2 illustrates a film casting line in which the method of the invention can be carried out. The method is schematically presented in Fig. 3e. Roll 21 of the line is a casting or quenching roll on which a polymer film is melt cast by means of an extrusion die 22. Molten polymer, e.g., film-forming poly(ethylene terephthalate), is extruded via die 22 onto the cooled, rotating roll 21 where it solidifies to form the film 23. The latter then passes through one or more selected processing stations which are represented schematically by block 24. These can include any of a number of processes such as film drafting and tentering, heat setting, coating of the film with photographic layers or the like and drying.

After the processing steps of block 24 where the web achieves its intended thickness prior to winding, the film is subjected to thickness measurements. Although in the method of the invention the thickness measurements can also be made off line on samples of the film, Fig. 2 depicts the embodiment in which on-line thickness measurements are made.

Fig. 2 shows the widthwise thickness measurements of the film being made continuously by traversing the measuring head across the web as the web passes through the instrument 25. The latter can be any of a number of contacting or non-contacting instruments for measuring film thicknesses. A preferred instrument is the Beta-Gauge Basis Weight Sensor of Measurex Corporation, Cupertino, California 95014, Model 2201/2202. This instrument measures the film thickness by sensing variations in Beta-ray transmission by the moving web. The lateral measurements are averaged in the lengthwise direction by the measuring instrument to obtain an average thickness distribution of the web. The values for the average thickness measurement, with other data, are input to the digital control computer 27 as shown in Fig. 2, which computer is programmed in accordance with Figs. 3a, b, c and d.

In the method of the invention, at least one of the winding conditions is adjusted or controlled to levels which avoid the formation of hardstreaks in the wound roll or reduce their severity to within acceptable tolerances. These adjustable winding conditions include the tension that is maintained in the web 23 during winding, the height of the thickened edges or knurls that are formed along the edges of the web and the extent to which the web is oscillated as it travels toward the winding roll. See Fig. 3e.

In Fig. 2 the first of the means for adjusting the web winding conditions is web oscillator or steering

frame guider 27 which is illustrated schematically. The web 23 first passes over an entry deflector roller 29 of guider 28, and passes vertically to a web entry roller 29, then horizontally to web exit roller 30. The rollers 29^1 and 30 are mounted in a horizontally oriented guide frame 34 which is mounted for reciprocating pivotal movement in a horizontal plane on a vertical pivot axis A-A. Leaving exit roller 30, the web passes over exit deflector roller 32 toward subsequent positions in the line.

The guide frame 28 can be reciprocally pivoted on axis A-A by conventional means, not shown in the drawing, to oscillate the path of the web as it moves toward the winding roll of the line. This is one effective means known in the art for laterally offsetting thickened portions of the web as it is wound and thus reducing the tendency toward formation of hardstreaks in the wound roll. Because of the lateral movement imparted to the moving web by this oscillation procedure, it is also referred to as "wiggle winding" and "stagger winding." Selection of optimum oscillation parameters, i.e., amplitude and frequency, is desirable because if the film path is not offset sufficiently the hardstreak problem is not sufficiently reduced but if the offset is too great the amount of edge waste that must be trimmed from the web is excessive.

One suitable apparatus for web oscillation is the web guiding apparatus disclosed in U.S. Patent No. 4,453,659, incorporated herein by reference. While the patent describes the use of the apparatus to correct web deviations, it can also be used to cause sinusoidal lateral oscillation of the web. Another useful apparatus is disclosed in U.S. Patent No. 2,672,299, incorporated herein by reference.

After leaving the steering frame 28, the edges of the web 23 are trimmed by the edge slitters 33 and 34

to remove edge waste caused by oscillation of the film and to form a straight edge.

Following the slitters 33 and 34, the web passes through another means for controlling winding conditions, namely, the knurling apparatus 35. This means, shown schematically in Fig. 2, includes two fixed wheels 36 and 37 positioned above web 23 and two adjustable wheels 39 positioned below the web. The web, optionally, is heated, e.g., ultrasonically as in U.S. Patent No. 4,247,273 (incorporated herein by reference) or otherwise, just before or during contact with the wheels. The wheels have patterned surfaces which, in known manner, are adapted to form thickened and knurled areas along the edges of the web. The edge thickness or knurl height depends upon the pressure applied by the adjustable wheels. This pressure is controlled in accordance with the invention by the control computer 27 to provide a knurl height which is sufficient to reduce hardstreak formation but is not so great as to cause the problems which are characteristic of excessively thickened edges.

After the knurling operation the web passes to a tension-controlling means 40. This comprises a fixed entry roller 41, a float roller 42 and a fixed exit roller 43. The force exerted by roller 42 to increase or decrease the web tension is also controlled in accordance with the invention by the control computer 27.

After passing the tension-controlling means, the web 23 is wound on the take-up roll or winder 45. Upon reaching this position the tension on the web has been controlled, the edge thickness has been controlled and the horizontal oscillation of the moving web has been controlled. These three conditions are controlled by the control computer 27. It determines from the thickness measurement by instrument 25 and from the

input data as to film properties and defect tolerances, the conditions required to wind the web without exceeding defect tolerances.

Although Fig. 2 shows the control of the three winding conditions, web tension, edge thickness and the oscillation parameters of amplitude and frequency, it should be understood that it is not always necessary to adjust all three of these conditions. In particular, if defects can be sufficiently reduced by adjusting only the edge thickness and the web tension, it may be preferred to omit the web oscillator, since this operation causes edge waste. However, if lengthwise persistent widthwise thickness variations are so great that defects cannot be sufficiently reduced without using web oscillation, the method of the invention can include the control of that operation as has been described.

The output of the digital computer 27 which controls the steering frame 28 is ported through an electromechanical drive (e.g., a servo motor). The output of the computer 27 which controls the knurl thickness is ported to a pneumatic actuator in the tension float roll 42. Conventional digital to analog interfaces can provide the necessary output porting.

Fig. 3e of the drawing illustrates how the analytical model for predicting web imperfections is used in the method of the invention. The inputs to the model 50 are the average thickness profile 51, the web properties 52 and the initial winding conditions 53. As previously indicated, the average thickness profile can be derived by off-line measurements of a portion of the web or by on-line measurements during winding of the web. The web properties are as previously defined. The initial winding conditions include the web tension, the edge thickness (knurl height) and the oscillation amplitude and frequency.

From these data the control computer executes the model as in Figs. 3a-3d and predicts the severity of web defects such as distortions, pressure damage to coated layers and blocking or adhesion of successive laps of the roll. As indicated by decision block 54 of Fig. 3e, these predicted values are compared with the tolerances input as indicated by block 55. If the predictions are within tolerances (OK), the initial winding conditions input (block 53) are updated or corrected (block 56) and used to control the winding tension, edge thickness and oscillation parameters for winding the roll 58, with the control means 40, 35 and 28 of Fig. 2.

If the predictions exceed tolerances, an optimization routine (Block 60) is executed, preferably using linear programming techniques as discussed in the Press et al. text cited herein. This provides new values to update the winding conditions, as indicated by Block 62, which are used in winding of the next roll to be produced. Thus, the measurements made for winding each roll are used to set the winding conditions for the next subsequent roll.

Figs. 3a-3e of the drawings illustrate the analytical model by means of which the method of the invention is controlled. Definitions of the terms used in said figures are listed in Table I below. The algorithim where the pressure, stress and strain parameters are computed is set forth in the article by the inventor hereof which appeared in the TAPPI Journal referenced below. The roll relaxation radii can be calculated using the polynomial extropolation algorithim in the text by Press et al. referenced below. Both of these literature articles are incorporated herein by reference.

Table I

Definitions:

ρ (i, j)	-	widthwise roll radius distribution, where i designates the lap number within the roll, which can vary between 0 for the core and N at the outside of the roll and j designates widthwise position.
R_O	-	relaxation radius, which is the roll radius at which the tension in the length direction is zero.
c (j)	-	widthwise outside core radius distribution, where j designates widthwise position.
N	-	number of laps in roll.
M	-	number of widthwise locations.
δ	-	width increment (web width divided by M).
MIN [ ]	-	minimum value in a vector of values.
EXC [x, y]	-	x-y for x > y. O otherwise
h (j)	-	average widthwise thickness profile, where j designates the widthwise location.

Table I cont'd

Φ_1	-	severity of pressure-induced winding imperfections.
S_1	-	imperfection sensitivity function for pressure.
Φ_2	-	same as ϕ_1 for tension.
S_2	-	same as S_1 for tension.
Φ_3	-	same as ϕ_1 for radial strain.
S_3	-	same as S_1 for radial strain.
Φ_4	-	same as ϕ_1 for tangental strain.
S_4	-	same as S_1 for tangental strain.
Φ	-	imperfection severity function.
c_k	-	weight factor for kth imperfection.
ε	-	tension tolerance.
EXT	-	polynominal extrapolation algorithm as described on pp. 80-83 of "Numerical Recipes, the Art of Scientific Computing" by V.H. Press et al., Cambridge University Press, 1986.

Table I cont'd

IRSN - non-linear algorithm for predicting in-roll stresses as described by Z. Hakiel in "Non-Linear Model for Wound Roll Stresses", TAPPI Journal, Vol. 70, No. 5 pp. 115-117, May 1987.

Fig. 4 of the drawing is a plot of the average thickness distribution for a poly(ethylene terephthalate) film of nominal 0.007 in. thickness. The plot is obtained by thickness measurements with a contacting off-line LVDT based profiler, but could have been obtained with a "Beta-guage" instrument as previously described. Fig. 4 plots the thickness in mils (0.001 in.) as the vertical axis against the widthwise locations. As the plot shows, at both edges the film is thicker than 7.5 mils, thus, identifying the presence of knurled or thickened edges. At intermediate points across the web, the average thickness varies from as low as about 6.9 mils to as high as about 7.3 mils.

Figs. 5, 6, 7, and 8 are predicted plots of roll diameters, the predictions being made by use of the analytical model of Figs. 3a-3d.

The following tables list the characteristics of the web and roll (Table II) as well as winding tension and knurl height (Table III) for the four predicted cases depicted in the plots of Figs. 5-8.

Table II

Web width	54 in.
Web thickness	0.007 in.
Knurl width	0.5 in. at each edge
Core diameter	5 in.
Roll diameter	15 in.
Elastic modulus of web	660,000 lb/in^2
Poisson's ratio of web	0.3

Table III

Fig.	Winding Tension (lb.)	Knurl Thickness (in.)
5	200	0.0073
6	110	0.0073
7	200	0.0075
8	110	0.0075

Fig. 5 shows the roll profile at successive roll radius during winding. Initially at 2.5 in. radius, the roll has a typically uneven profile such as in Fig. 4. Then as the roll is wound at a winding tension of 200 lb. and with the film having a knurl height of 0.0073 inch at each edge, the roll surface progressively begins to develop hardstreaks. When the roll radius has reached 7.5 in. (the uppermost plot of Fig. 5) two severe hardstreaks A and B are apparent.

The flat portion of this plot and others in Figs. 6-8, represent the relaxation radius, R_o, of the roll.

Fig. 6 plots the predicted roll profile at successive stages for a roll being wound at a lower winding tension of 110 lbs and having a knurl height as in Fig. 5, namely, 0.0073. Again as in Fig. 5, at a radius of 2.5 inches, the roll has the typical surface variations exhibited in Fig. 5. As winding proceeds and

the roll radius increases to 7.5 inches, (the uppermost plot) two smaller hardstreaks than in Fig. 5, develop in the roll.

Fig. 7 is a similar series of plots for a roll being wound at 200 lbs tension but with greater knurl height, i.e., 0.0075 inch. The traces progressing from bottom to top (from 2.5 to 7.5 inches) show a radius steadily improving surface regularity. At 7.5 inches the hardstreak is barely noticeable.

Fig. 8 is another series of such plots for a roll being wound at 110 lbs. tension and with a greater knurl height, i.e. 0.00075 in. Under these conditions, at 7.5 inches, the roll is essentially free of hardstreaks.

Although the invention has been described specifically with reference to the winding of a melt-cast poly(ethylene terephthalate) web, it should be understood that the method can be used for controlling and reducing the formation of hardstreaks in the winding of a wide range of plastic webs. Other melt cast polymeric webs such as polyolefins are examples, as well as solvent-cast webs such as cellulose esters and especially cellulose triacetate.

This invention has been described in detail with particular reference to preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

CLAIMS

1. The method of winding on cores plastic webs having thickened edges which comprises:

measuring properties of a web to be wound on a core including:

(a) modulus of elasticity of the plastic,

(b) stack-wise compression modulus of the web,

(c) stack-wise compression modulus of the thickened edges,

(d) Poisson's ratio of the plastic,

(e) stress relaxation modulus of the web,

selecting initial winding conditions for

(a) initial web tension,

(b) initial edge thickness, and

(c) initial web oscillation;

iteratively measuring widthwise thickness variations of said web at lengthwise locations on the web,

averaging the measured widthwise thickness variations in the lengthwise direction to obtain an average widthwise thickness distribution for the web,

measuring the core modulus and the width and diameter of the core,

predicting the severity of winding imperfections from the relationship of (1) said properties, (2) the average widthwise thickness distribution of the web, (3) the initial winding conditions and (4) said measurements of the core,

comparing the predicted imperfections with predetermined tolerances to determine whether the imperfections are within or exceed the tolerances;

when said predicted imperfections are within the tolerances, winding the first web on a core at said initial winding conditions; and

when said predicted imperfections exceed the tolerances, winding the web on the core under corrected winding conditions for at least one of web tension, edge thickness and web oscillation.

2. The method according to claim 1 wherein the severities of winding imperfections, Φ, are predicted by means of the analytical model of Figs. 3a and 3b, the parameters of which are defined in Table I.

3. The method according to claim 1 which comprises winding a second web at initial winding conditions corresponding to the corrected values for the first web.

4. The method according to claim 1 wherein said measurements are collected upon winding of a first web on said core, said winding conditions are then computed based upon the collected measurements and a second web is wound on said core under said computed winding conditions.

5. The method according to claim 1 wherein said averaging, predicting and winding condition establishing steps are carried out with the aid of a digital computer.

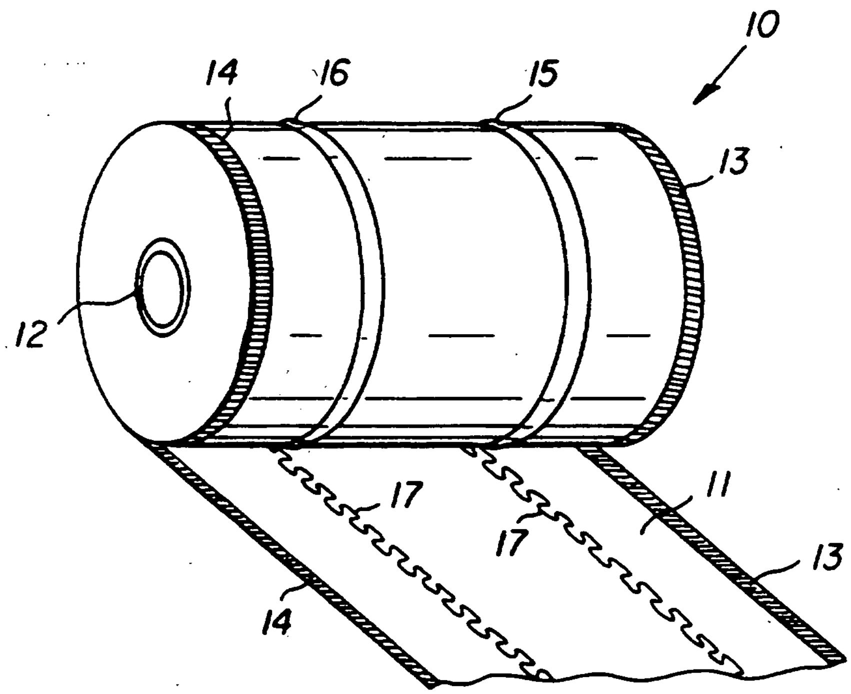


FIG. 1

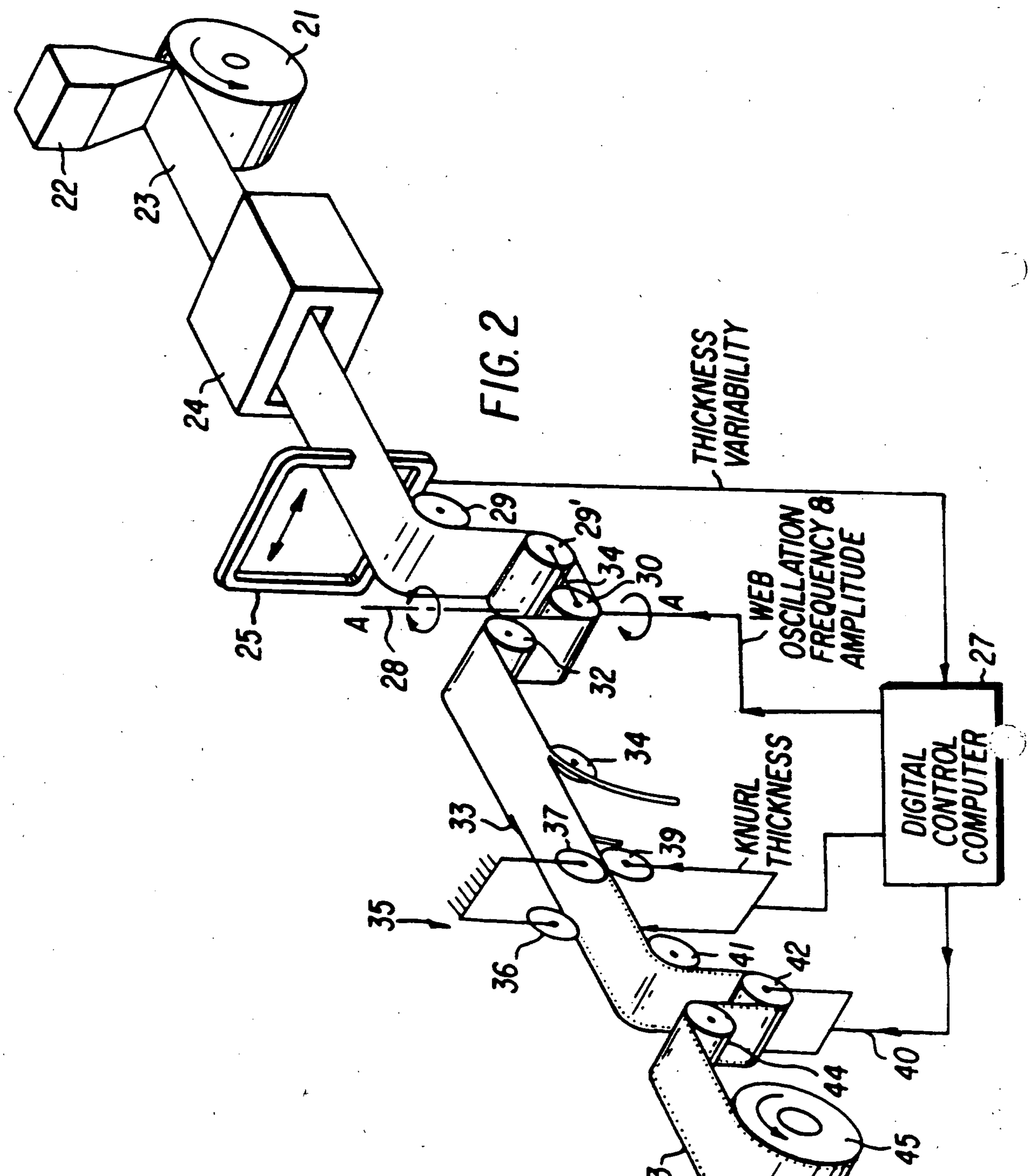

THICKNESS VARIABILITY
WEB OSCILLATION FREQUENCY & AMPLITUDE
KNURL THICKNESS
DIGITAL CONTROL COMPUTER
21
22
23
24
25
27
28
29
29'
30
32
33
34
35
36
37
39
40
41
42
44
45
A

FIG. 2

3/12

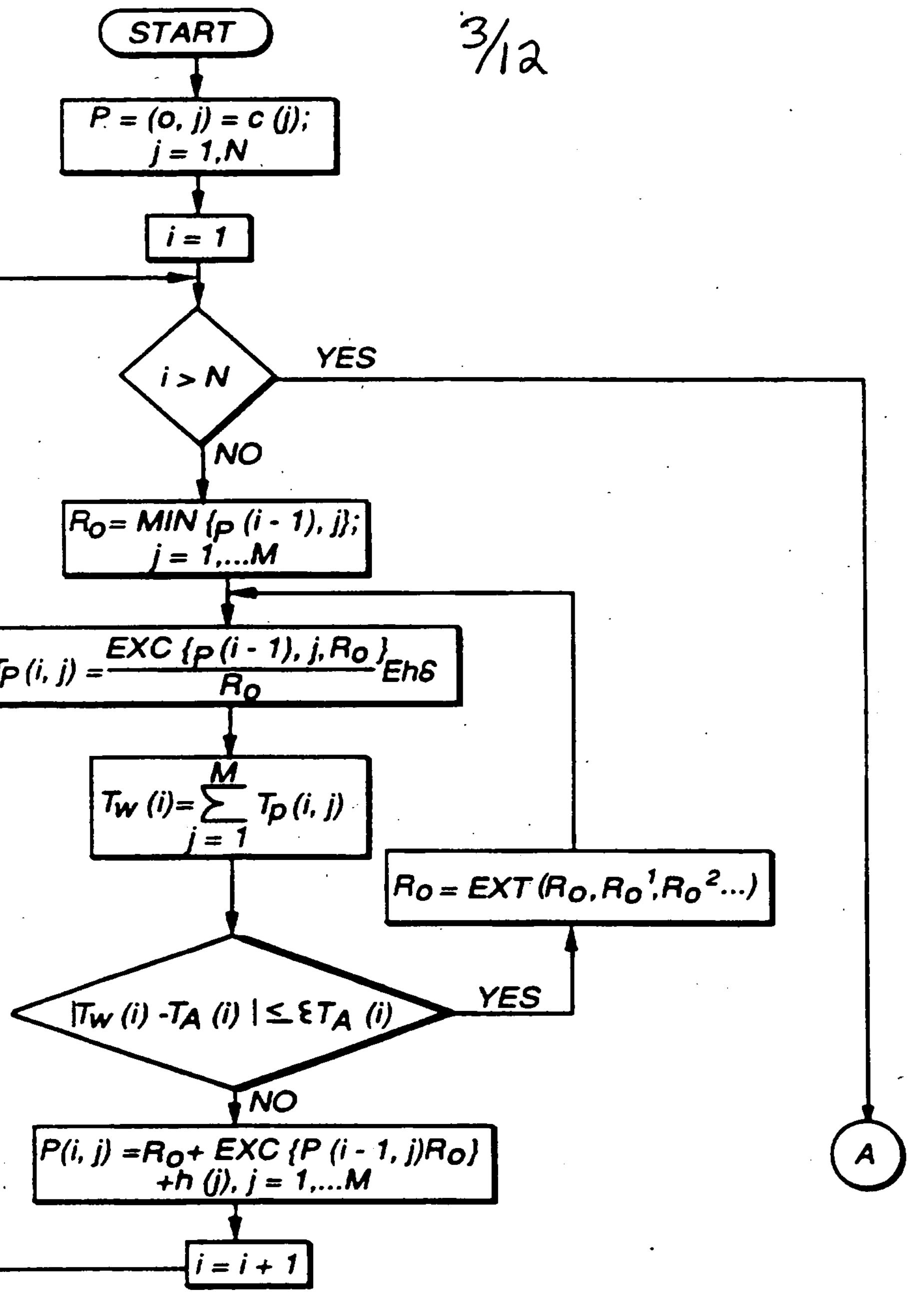

START
P = (o, j) = c (j);
j = 1,N
i = 1
i > N
YES
NO
Ro= MIN {p (i - 1), j};
j = 1,...M
Tp (i, j) = EXC {p (i - 1), j, Ro} / Ro Ehδ
Tw (i)= Σ j = 1 M Tp (i, j)
Ro = EXT (Ro, Ro1, Ro2...)
|Tw (i) -TA (i) | ≤ εTA (i)
YES
NO
P(i, j) =Ro+ EXC {P (i - 1, j)Ro}
+h (j), j = 1,...M
i = i + 1
A

FIG. 3A

4/12

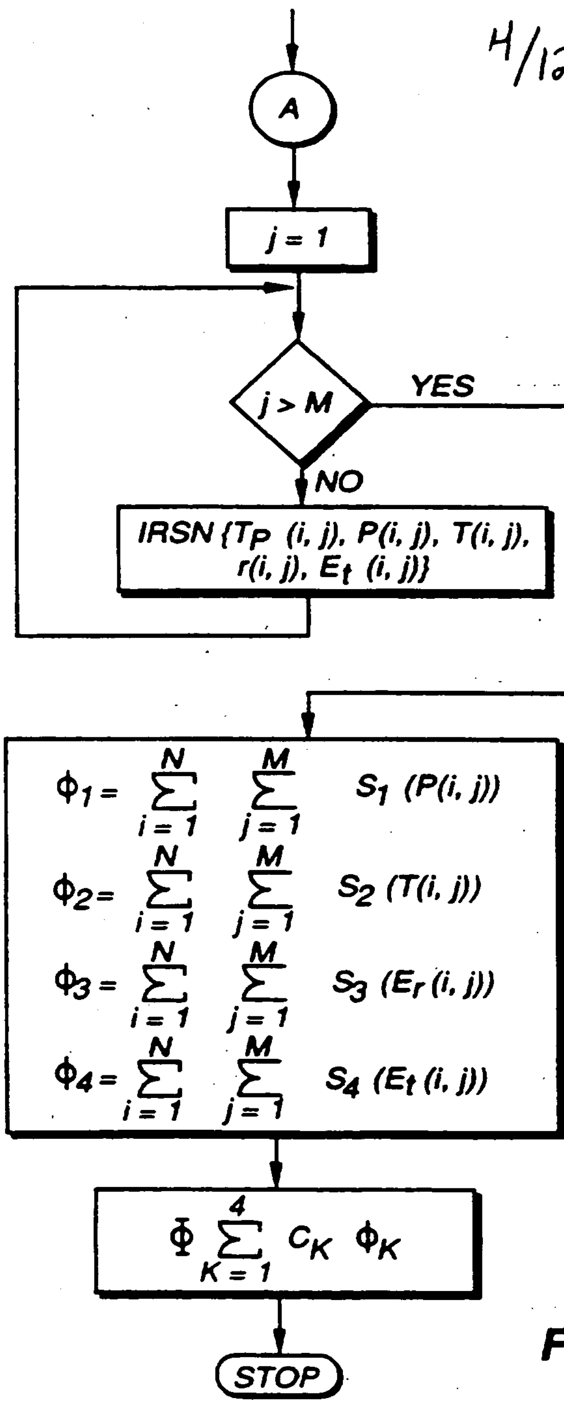

A
j = 1
j > M
YES
NO
IRSN {T_P (i, j), P(i, j), T(i, j), r(i, j), E_t (i, j)}
$\Phi_1 = \sum_{i=1}^{N} \sum_{j=1}^{M} S_1 (P(i, j))$
$\Phi_2 = \sum_{i=1}^{N} \sum_{j=1}^{M} S_2 (T(i, j))$
$\Phi_3 = \sum_{i=1}^{N} \sum_{j=1}^{M} S_3 (E_r (i, j))$
$\Phi_4 = \sum_{i=1}^{N} \sum_{j=1}^{M} S_4 (E_t (i, j))$
$\Phi \sum_{K=1}^{4} c_K \Phi_K$
STOP

FIG. 3B

5/12

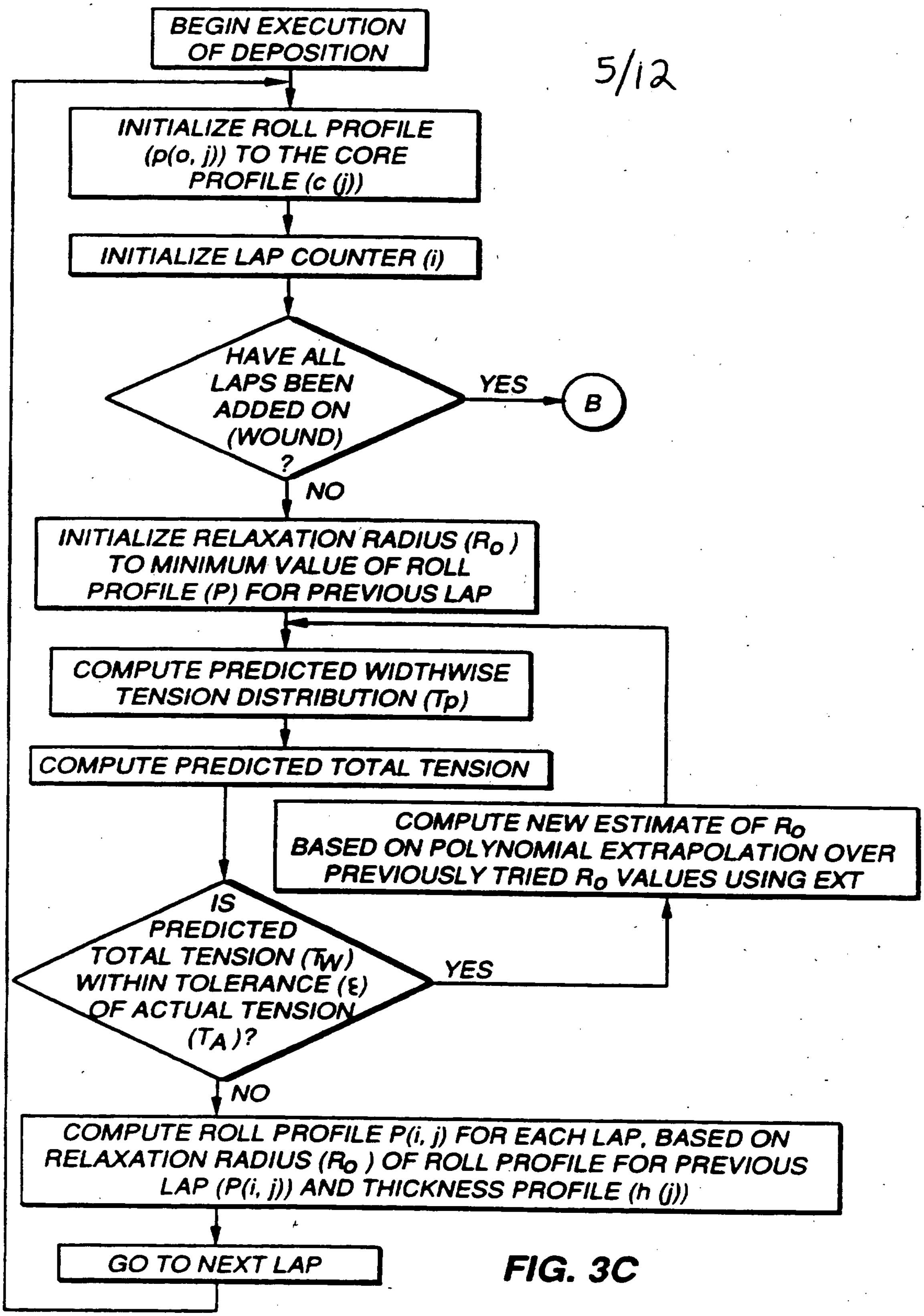

BEGIN EXECUTION OF DEPOSITION
INITIALIZE ROLL PROFILE (p(o, j)) TO THE CORE PROFILE (c (j))
INITIALIZE LAP COUNTER (i)
HAVE ALL LAPS BEEN ADDED ON (WOUND) ?
YES
B
NO
INITIALIZE RELAXATION RADIUS (R_o) TO MINIMUM VALUE OF ROLL PROFILE (P) FOR PREVIOUS LAP
COMPUTE PREDICTED WIDTHWISE TENSION DISTRIBUTION (T_P)
COMPUTE PREDICTED TOTAL TENSION
COMPUTE NEW ESTIMATE OF R_o BASED ON POLYNOMIAL EXTRAPOLATION OVER PREVIOUSLY TRIED R_o VALUES USING EXT
IS PREDICTED TOTAL TENSION (T_W) WITHIN TOLERANCE (ε) OF ACTUAL TENSION (T_A)?
YES
NO
COMPUTE ROLL PROFILE P(i, j) FOR EACH LAP, BASED ON RELAXATION RADIUS (R_o) OF ROLL PROFILE FOR PREVIOUS LAP (P(i, j)) AND THICKNESS PROFILE (h (j))
GO TO NEXT LAP

FIG. 3C

6/12

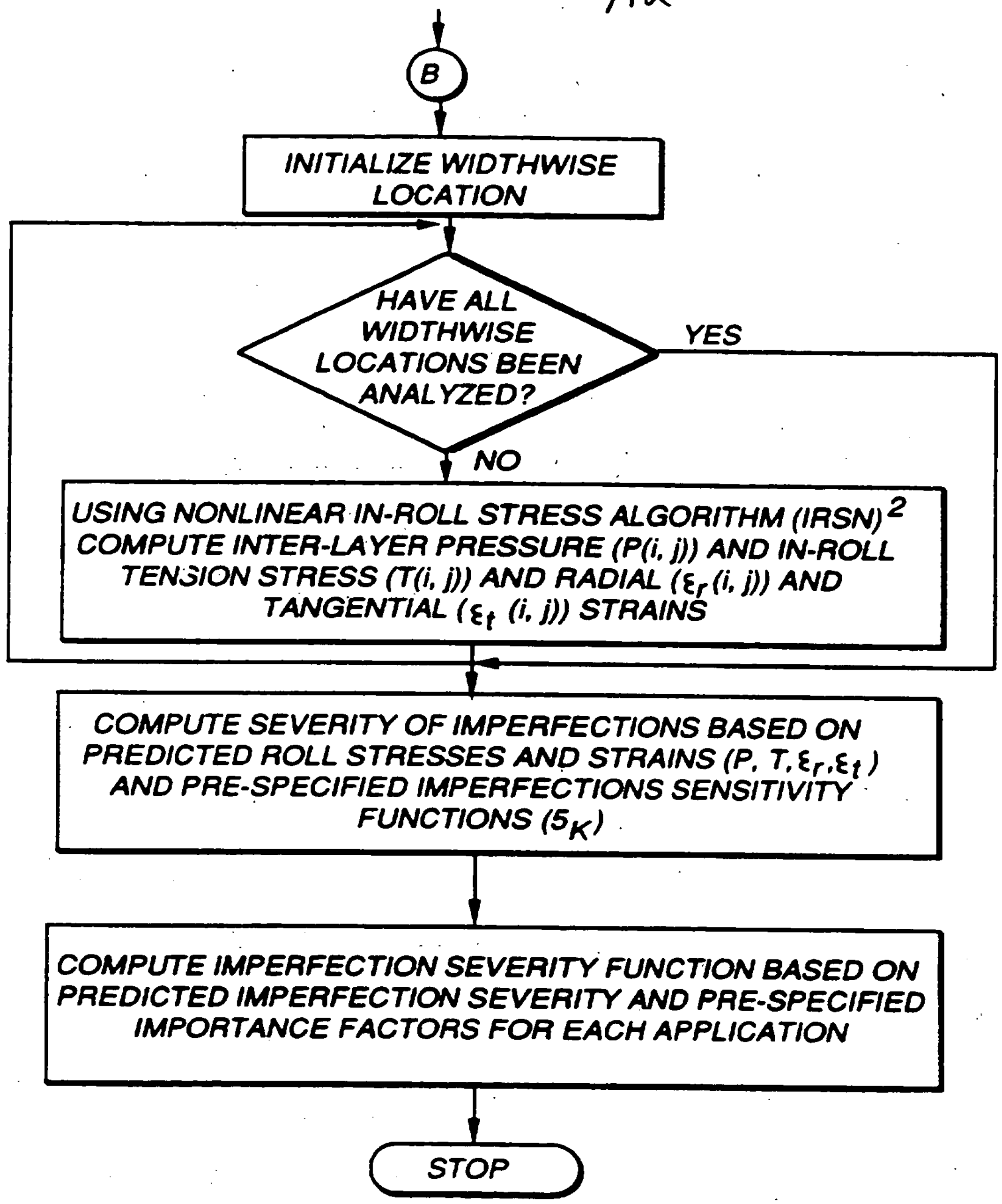

B
INITIALIZE WIDTHWISE LOCATION
HAVE ALL WIDTHWISE LOCATIONS BEEN ANALYZED?
YES
NO
USING NONLINEAR IN-ROLL STRESS ALGORITHM (IRSN)[2] COMPUTE INTER-LAYER PRESSURE (P(i, j)) AND IN-ROLL TENSION STRESS (T(i, j)) AND RADIAL (ε_r(i, j)) AND TANGENTIAL (ε_t (i, j)) STRAINS
COMPUTE SEVERITY OF IMPERFECTIONS BASED ON PREDICTED ROLL STRESSES AND STRAINS (P, T, ε_r, ε_t) AND PRE-SPECIFIED IMPERFECTIONS SENSITIVITY FUNCTIONS (5_K)
COMPUTE IMPERFECTION SEVERITY FUNCTION BASED ON PREDICTED IMPERFECTION SEVERITY AND PRE-SPECIFIED IMPORTANCE FACTORS FOR EACH APPLICATION
STOP

FIG. 3D

7/12

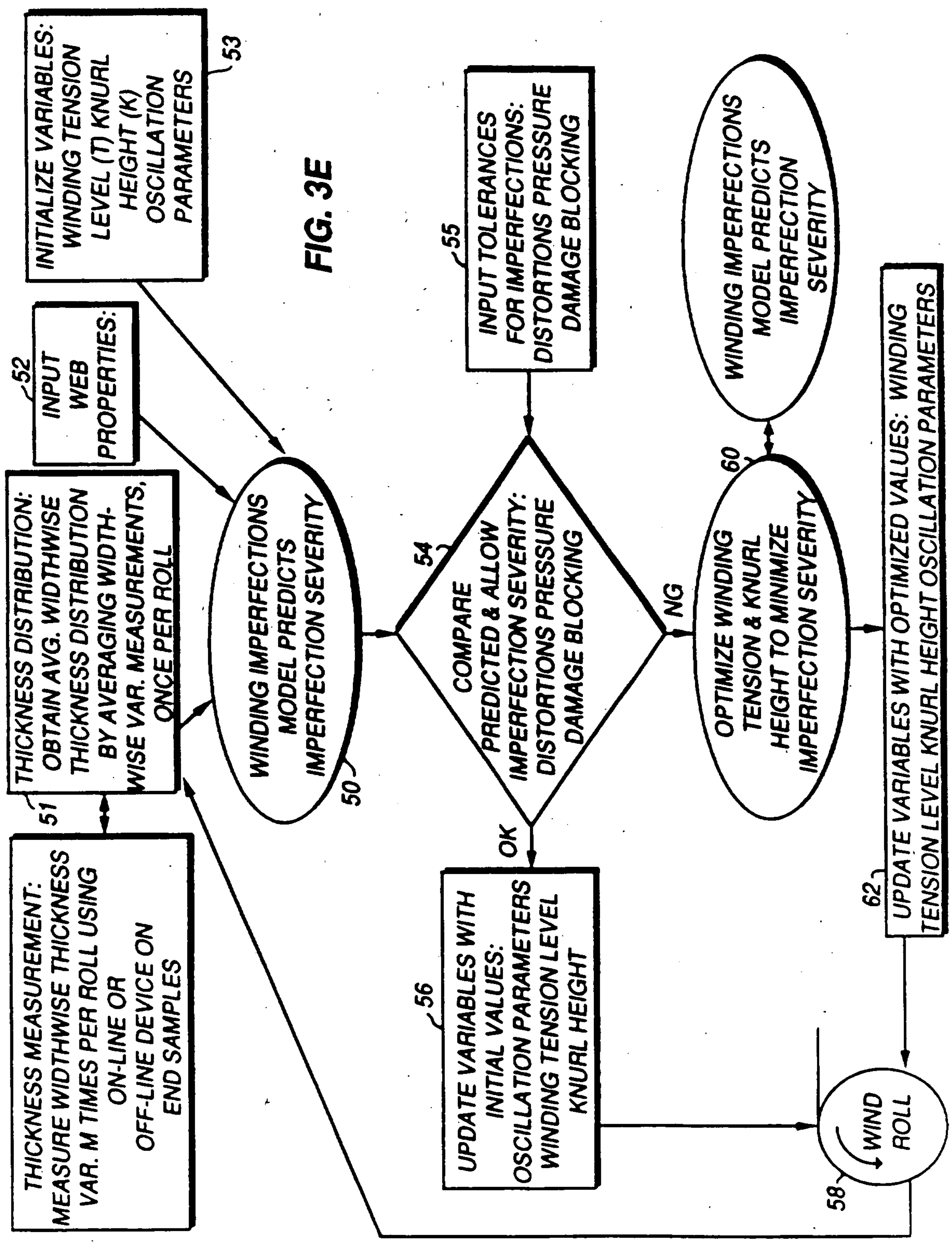

THICKNESS MEASUREMENT: MEASURE WIDTHWISE THICKNESS VAR. M TIMES PER ROLL USING ON-LINE OR OFF-LINE DEVICE ON END SAMPLES
51
THICKNESS DISTRIBUTION: OBTAIN AVG. WIDTHWISE THICKNESS DISTRIBUTION BY AVERAGING WIDTH-WISE VAR. MEASUREMENTS, ONCE PER ROLL
52
INPUT WEB PROPERTIES:
INITIALIZE VARIABLES: WINDING TENSION LEVEL (T) KNURL HEIGHT (K) OSCILLATION PARAMETERS
53
WINDING IMPERFECTIONS MODEL PREDICTS IMPERFECTION SEVERITY
50
56
UPDATE VARIABLES WITH INITIAL VALUES: OSCILLATION PARAMETERS WINDING TENSION LEVEL KNURL HEIGHT
OK
54
COMPARE PREDICTED & ALLOW IMPERFECTION SEVERITY: DISTORTIONS PRESSURE DAMAGE BLOCKING
55
INPUT TOLERANCES FOR IMPERFECTIONS: DISTORTIONS PRESSURE DAMAGE BLOCKING
NG
OPTIMIZE WINDING TENSION & KNURL HEIGHT TO MINIMIZE IMPERFECTION SEVERITY
60
WINDING IMPERFECTIONS MODEL PREDICTS IMPERFECTION SEVERITY
58
WIND ROLL
62
UPDATE VARIABLES WITH OPTIMIZED VALUES: WINDING TENSION LEVEL KNURL HEIGHT OSCILLATION PARAMETERS

FIG. 3E

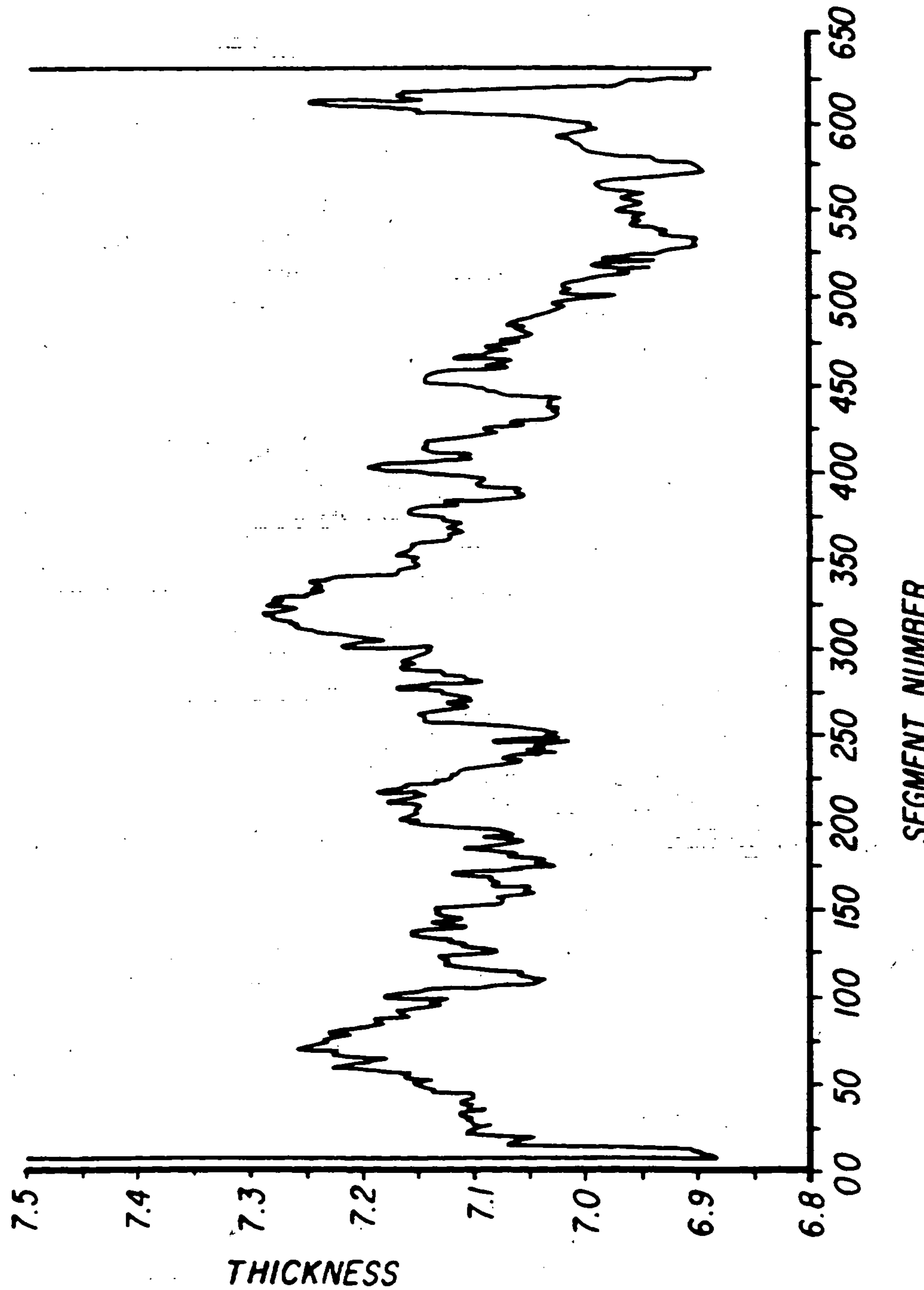

THICKNESS
7.5
7.4
7.3
7.2
7.1
7.0
6.9
6.8
SEGMENT NUMBER
00
50
100
150
200
250
300
350
400
450
500
550
600
650

FIG. 4

FIG. 5

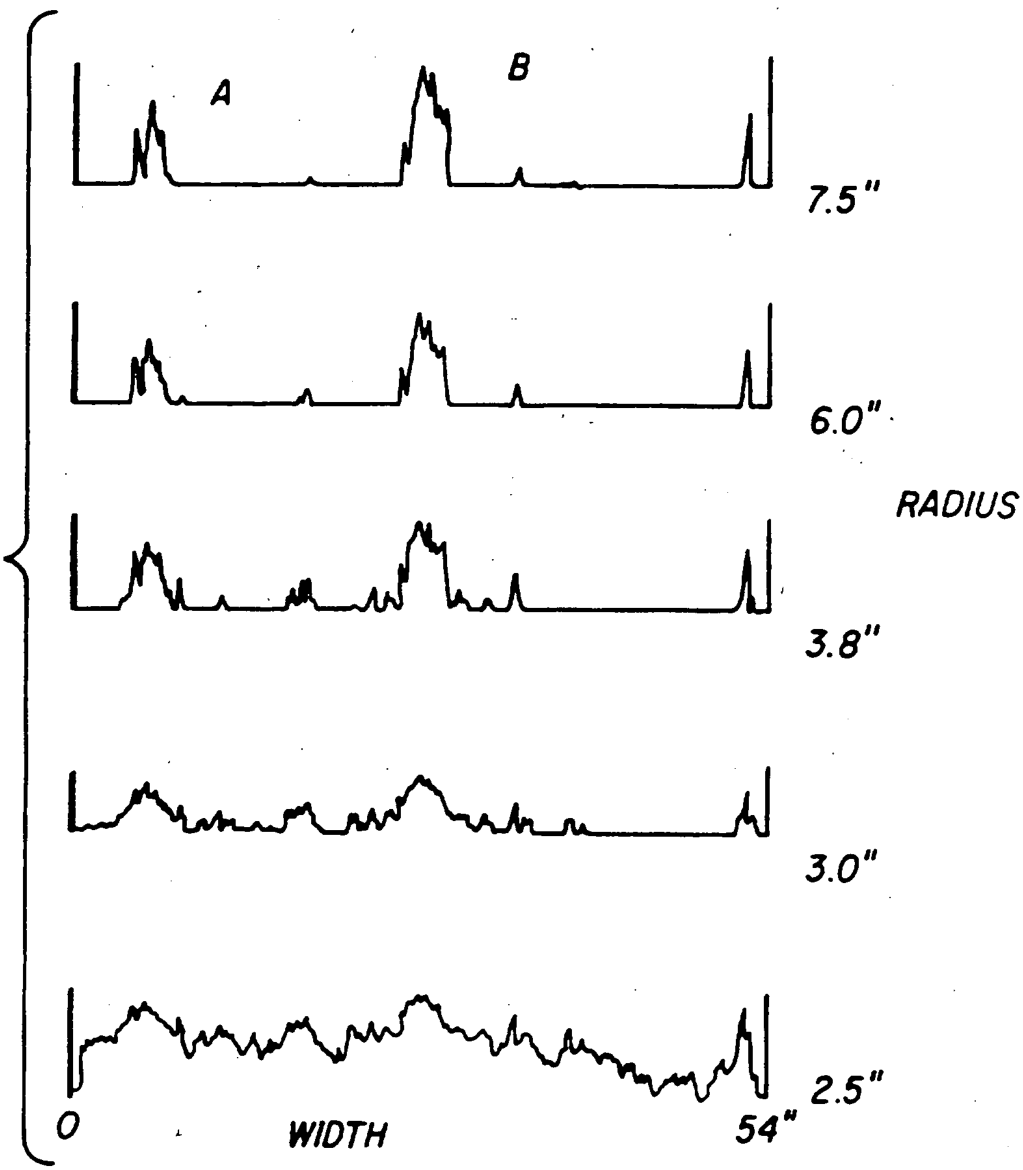


FIG. 6

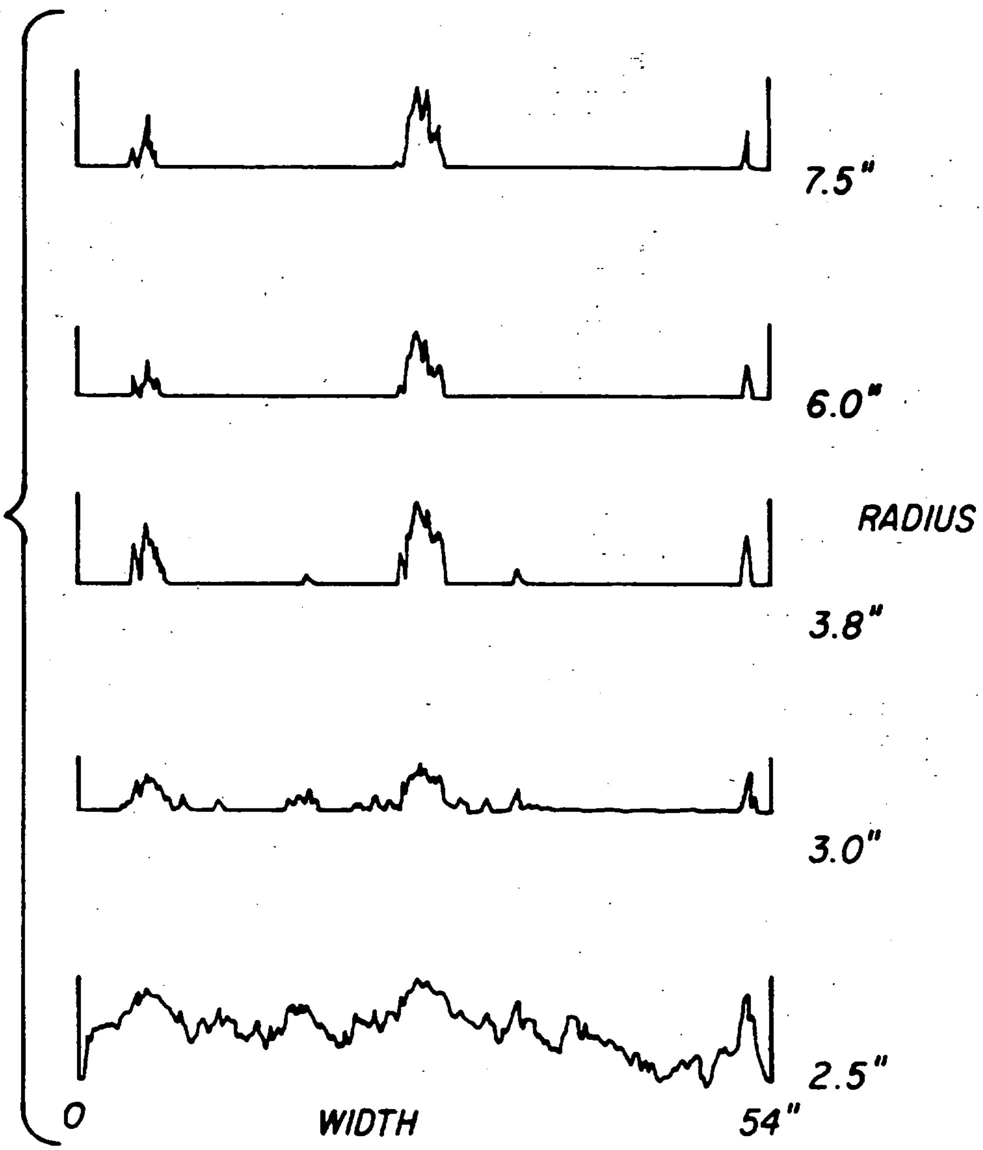


FIG. 7

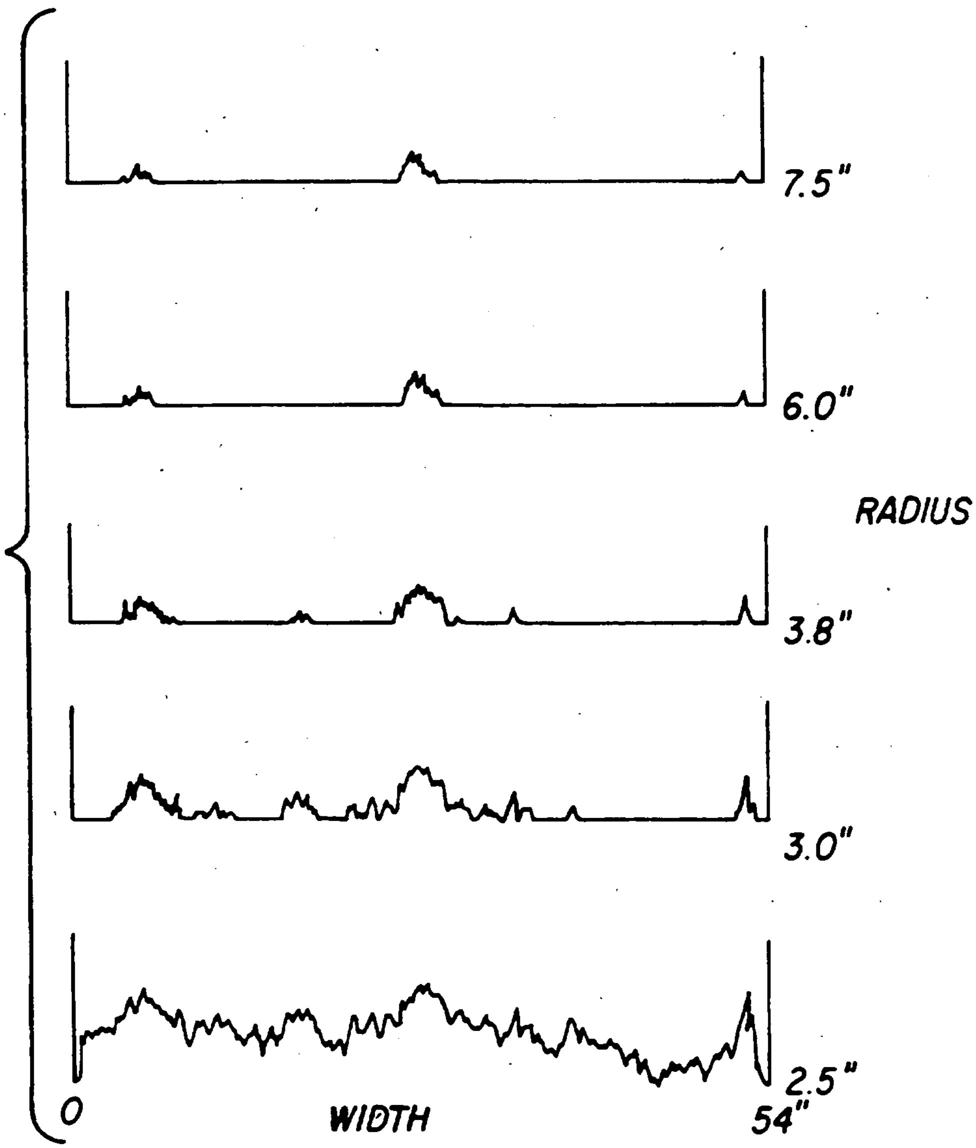
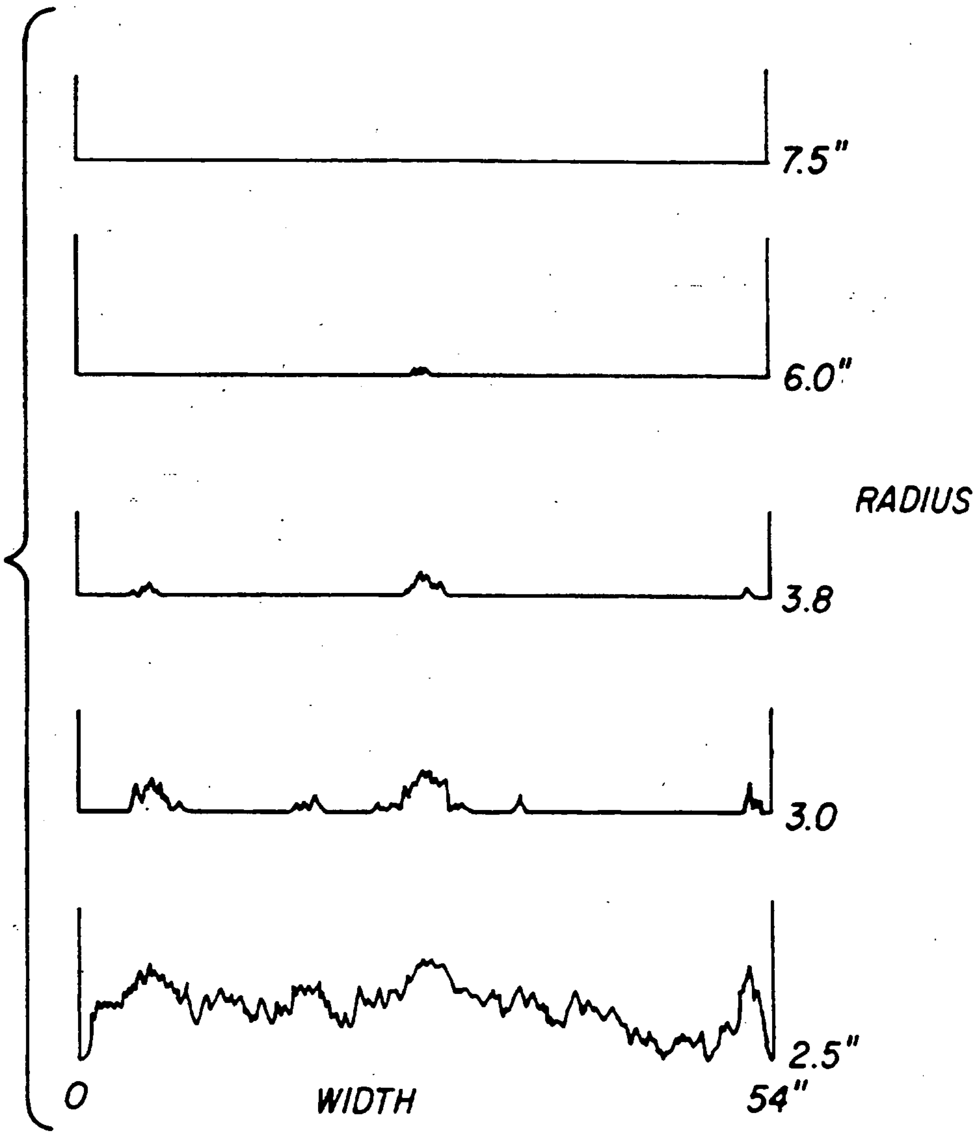


FIG. 8



INTERNATIONAL SEARCH REPORT

International Application No PCT/US 92/03525

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 B65H26/02

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	B65H

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category °	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
A	US,A,4 535 950 (INTERNATIONAL PAPER COMPANY) 20 August 1985 see column 5, line 27 - column 7, line 13; claims 8,9; figures 1,3,4 ---	1
A	PATENT ABSTRACTS OF JAPAN vol. 8, no. 274 (M-345)14 December 1984 & JP,A,59 143 837 (FUJI TEKKOSHO K.K.) 17 August 1984 see abstract ---	1,5
A	TAPPI. vol. 62, no. 10, October 1979, ATLANTA US pages 83 - 85; PFEIFFER D.: 'PREDICTION OF ROLL DEFECTS FROM ROLL STRUCTURE FORMULAS' see abstract --- -/--	1

° Special categories of cited documents : [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
14 SEPTEMBER 1992	24.09.92
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	THIBAUT E.E.G.C.

2

Form PCT/ISA/210 (second sheet) (January 1985)

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category °	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	TAPPI. vol. 58, no. 8, August 1975, ATLANTA US pages 152 - 155; MONK D.W., LAUTNER W.K., MCMULLEN J.F.: 'INTERNAL STRESSES WITHIN ROLLS OF CELLOPHAN' See page 152, paragraph : "calculation of radial compressive pressure and circumferential film tension" See page 155, paragraph: "Conclusions" ---	1

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. US 9203525 SA 60280

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 14/09/92
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US-A-4535950	20-08-85	CA-A-	1229151	10-11-87

EPO FORM P0479

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82